

**ASSESSMENT AND EVALUATION OF THE
NAVAL BIODYNAMICS LABORATORY
X-RAY ANTHROPOMETRY SYSTEM**

[M]² Systems, Incorporated
Clifford J. Mugnier

Final Technical Report

~~4 May 1990~~

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13. ABSTRACT (Maximum 200 words) The major objective sought for this research effort are to define the current system accuracy and to provide guidance for improvements in the procedures, methodology and accuracy of the X-Ray Anthropometry system use at NBDL. The current software system is a series of FORTRAN programs written over a number of years with minimal documentation. The success of this report included the implementation of one or more rigorous analytical photogrammetry packages and systems to provide a reliable computational tool with the capability to compute the geometric dilution of precision.				
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NEW ORLEANS, LOUISIANA 70122

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FINAL TECHNICAL REPORT

Assessment and Evaluation of the
Naval Biodynamics Laboratory
X-Ray Anthropometry System

Contract No. N00205-90-M-D146

CONSULTING IN

CARTOGRAPHY

GEODESY

PHOTOGRAMMETRY

MATHEMATICAL RESEARCH

COMPUTER SOFTWARE

OPTICAL INSTRUMENTATION



ANALYSIS SYSTEMS

The major objectives sought for this research effort are to define the current system accuracy and to provide guidance for improvements in the procedures, methodology and accuracy of the X-Ray Anthropometry system used at the Naval Biodynamics Laboratory.

Inspection of the current procedures was performed, and the X-Ray facilities were observed while in operation for a demonstration of a typical series of X-Rays of a research subject. The current software system is a series of FORTRAN programs written over a number of years with minimal documentation. There is no provision for rigorous weighting or for computing the geometric dilution of precision in the X-Ray photogrammetry. The tasks necessary to complete in order to achieve the objectives of this research included the implementation of one or more rigorous analytical photogrammetry packages & systems to provide a reliable computational tool with the capability to compute the geometric dilution of precision.

Packages successfully implemented under the MS-DOS operating system are:

- PREP - Preprocessor for Film Shrinkage compensation
- GHOSH - Initial camera calibration and analytical photogrammetry package.
- GIANT - Virtually unlimited analytical photogrammetry package with complete error propagation facility for Geometric Dilution of Precision.
- CHURCH - Analytical photogrammetry utility package for space resections of X-Ray Source positions.

Of the above packages, only GIANT (the most complex) has not been successfully installed on the Hewlett-Packard HP 9000 UNIX system. However, the packages had sufficient flexibility under MS-DOS to complete the requisite limited analyses.

SYSTEM CALIBRATION

Current techniques for X-Ray system calibration involve the use of a lucite prism with lead shot (BB's) permanently imbedded at precisely known positions. This object is then simultaneously exposed onto two photographic plates (Anterior-Posterior "AP") and (Lateral "LAT") that are oriented ninety degrees to each other. Algorithms then solve for the perspective centers (X-Ray Source or Camera Station Positions & Attitudes) and principal distances (Focal Lengths). This information is ephemeral; after a given subject series is imaged, subsequent series each need re-calibration. Image coordinates are digitized by tracing the the imaged points of interest onto a sheet of paper with felt-tip pens and then located by an X-Y plotter. The repeatability of such a system has dubious results at best, and is remarkably time-consuming and prone to error.

X-Ray plates were exposed for calibration prism imagery as well as for Rhesus imagery. The following three pages are example PREP runs of LAT imagery of the Prism with 3-parameter, 4-parameter and 8-parameter transformations of the data points with respect to the Film Shrinkage points and other points commonly referred to as "Y=Axis" and "Origin". Note that the digitized data presented in this report was digitized on a 9" X 18" MANN Monocomparator with an accuracy and repeatability of better than plus or minus +/- one micrometer (1/1000th of a millimeter).

AP & LAT PREF RUNS OF PRISM DATA FOR INPUT TO GIANT:

* M-SQUARED SYSTEMS, INC. *
FIDUCIAL MEASUREMENTS OF FRAME 123

ID	AVERAGE		MAX SPREAD	
	X	Y	X	Y
111	155.688	30.306	0.000	0.000
222	150.325	184.829	0.000	0.000
333	459.722	191.732	0.000	0.000
444	465.501	36.154	0.000	0.000

3-PARAMETER RESIDUALS OF THE FIDUCIAL COORDINATES

111	-0.072	0.025
222	-0.024	0.042
333	-0.109	-0.021
444	0.205	-0.046

PLATE COORDINATES

ID	MEASURED		ADJUSTED		MAX SPREAD		FRAME
	X	Y	X	Y	X	Y	
5	210.964	237.646	-93.078	128.877	0.000	0.000	123
6	205.199	14.219	-103.492	-94.382	0.000	0.000	123
7	428.654	18.594	120.005	-94.659	0.000	0.000	123
8	421.948	242.060	117.953	128.898	0.000	0.000	123
9	431.541	131.678	125.246	18.340	0.000	0.000	123
10	319.421	131.123	13.138	20.119	0.000	0.000	123
11	179.030	131.092	-127.223	23.011	0.000	0.000	123
12	322.585	0.170	13.576	-110.871	0.000	0.000	123

* M-SQUARED SYSTEMS, INC. *
FIDUCIAL MEASUREMENTS OF FRAME 123

ID	AVERAGE		MAX SPREAD	
	X	Y	X	Y
111	155.688	30.306	0.000	0.000
222	150.325	184.829	0.000	0.000
333	459.722	191.732	0.000	0.000
444	465.501	36.154	0.000	0.000

4-PARAMETER RESIDUALS OF THE FIDUCIAL COORDINATES

111	-0.029	0.047
222	0.019	0.020
333	-0.152	-0.042
444	0.162	-0.025

PLATE COORDINATES

ID	MEASURED		ADJUSTED		MAX SPREAD		FRAME
	X	Y	X	Y	X	Y	
5	210.964	237.646	-93.051	128.841	0.000	0.000	123
6	205.199	14.219	-103.463	-94.356	0.000	0.000	123
7	428.654	18.594	119.972	-94.633	0.000	0.000	123
8	421.948	242.060	117.920	128.862	0.000	0.000	123
9	431.541	131.678	125.211	18.335	0.000	0.000	123
10	319.421	131.123	13.135	20.114	0.000	0.000	123
11	179.030	131.092	-127.187	23.004	0.000	0.000	123
12	322.585	0.170	13.572	-110.841	0.000	0.000	123

* M-SQUARED SYSTEMS, INC. *

APR 1988 VERSION

C. J. MUGNIER

CALIBRATED FIDUCIAL COORDINATES

111	-152.586	-77.293
222	-154.779	77.292
333	154.780	77.815
444	157.005	-77.824

FIDUCIAL MEASUREMENTS OF FRAME 'LAT'

ID	AVERAGE		MAX SPREAD	
	X	Y	X	Y
111	155.688	30.306	0.000	0.000
222	150.325	184.829	0.000	0.000
333	459.722	191.732	0.000	0.000
444	465.501	36.154	0.000	0.000

8-PARAMETER RESIDUALS OF THE FIDUCIAL COORDINATES

111	0.000	0.000
222	0.000	0.000
333	0.000	0.000
444	0.000	0.000

PLATE COORDINATES

ID	MEASURED		ADJUSTED		MAX SPREAD		FRAME
	X	Y	X	Y	X	Y	
5	210.964	237.646	-93.027	128.922	0.000	0.000	LAT
6	205.199	14.219	-103.463	-94.372	0.000	0.000	LAT
7	428.654	18.594	119.806	-94.597	0.000	0.000	LAT
8	421.948	242.060	118.142	128.983	0.000	0.000	LAT
9	431.541	131.678	125.242	18.321	0.000	0.000	LAT
10	319.421	131.123	13.159	20.077	0.000	0.000	LAT
11	179.030	131.092	-127.184	22.939	0.000	0.000	LAT
12	322.585	0.170	13.473	-110.807	0.000	0.000	LAT
13	351.403	53.228	12.505	151.127	0.000	0.000	LAT

GHOSH CALIBRATION RUN FOR DETERMINATION OF FOCAL LENGTHS OF X-RAY CAMERAS:

LAT TEST CALIBRATION FOR X-RAY CAMERAS

WEIGHT ON PHOTO COORDINATES = 1.60000E+01

SURVEY COORDINATES AND STD ERRORS

PT NO	X	Y	Z	WX	WY	WZ
5	0.000	0.062	0.254	2.50E-04	2.50E-04	2.50E-04
6	0.000	0.051	0.051	2.50E-04	2.50E-04	2.50E-04
7	0.000	0.254	0.051	2.50E-04	2.50E-04	2.50E-04
8	0.000	0.254	0.254	2.50E-04	2.50E-04	2.50E-04
9	0.051	0.254	0.152	2.50E-04	2.50E-04	2.50E-04
10	0.152	0.152	0.152	2.50E-04	2.50E-04	2.50E-04
11	0.254	0.051	0.152	2.50E-04	2.50E-04	2.50E-04
12	0.152	0.152	0.051	2.50E-04	2.50E-04	2.50E-04
13	0.152	0.152	0.254	2.50E-04	2.50E-04	2.50E-04

PHOTO 1

	1.0500	0.2000	0.2000	90.0000	90.0000	0.0000
	6.25E+02	6.25E+02	6.25E+02	1.00E+02	1.00E+02	1.00E+02
5	-93.027	128.922				
6	-103.463	-94.372				
7	119.806	-94.597				
8	118.142	128.983				
9	125.242	18.321				
10	13.159	20.077				
11	-127.184	22.939				
12	13.473	-110.807				
13	12.505	151.127				

PHOTO 2

	1.0600	0.2100	0.2100	0.0000	90.0000	90.0000
	6.25E+02	6.25E+02	6.25E+02	1.00E+02	1.00E+02	1.00E+02
5	-93.027	128.922				
6	-103.463	-94.372				
7	119.806	-94.597				
8	118.142	128.983				
9	125.242	18.321				
10	13.159	20.077				
11	-127.184	22.939				
12	13.473	-110.807				
13	12.505	151.127				

RESIDUALS FROM OBSERVATION EQUATION BEFORE 1ST CYCLE

PHOTO	PT	RES. in X	RES. in Y
1	5	54.212	71.487
1	6	55.634	64.487
1	7	62.614	64.189
1	8	61.015	71.490
1	9	65.160	71.543
1	10	72.740	79.362
1	11	82.619	89.836
1	12	73.017	74.982
1	13	72.124	83.908
2	5	63.031	82.245
2	6	64.331	73.190
2	7	73.367	72.901
2	8	71.764	82.246
2	9	76.498	81.761
2	10	84.064	90.693
2	11	93.535	102.540
2	12	84.339	84.908
2	13	83.450	96.635

ITERATION 3
VARIANCE = 10.929
Degrees of Freedom = 36

INTERIOR ORIENTATION

	X	Y	f
	-10.35	-0.61	-1118.14
STD ERROR	2.72	2.79	3.30
WEIGHT	1.00E+00	1.00E+00	1.00E+00
	K1(D-6)	K2(D-12)	K3(D-18)
	-0.55	0.48	0.03
STD ERROR	0.39	3.29	3.31
WEIGHT	1.00E+00	1.00E+00	1.00E+00
	P1(D-6)	P2(D-12)	P3(D-18)
	1.39	0.00	0.00
STD ERROR	3.26	3.31	3.31
WEIGHT	1.00E+00	1.00E+00	1.00E+00

COVARIANCE/VARIANCE/CORRELATION COEFFICIENT MATRIX

ROW 1

1.000000E+00	-2.346819E-03	-1.581831E-02
-2.668310E-02	1.177548E-02	6.929133E-04
5.085410E-02	-2.858162E-09	2.253158E-15
5.547703E-02	4.246953E-01	-1.046218E-02
3.323813E-03	-2.716295E-01	-3.253701E-03
8.131903E-02	9.850321E-01	-5.565664E-03
1.200360E-02	-6.366484E-04	-1.188562E-02

ROW 2

-2.346819E-03	1.000000E+00	1.229280E-03
7.202371E-02	3.891926E-03	2.876543E-04
-3.649276E-03	3.760610E-08	-1.779299E-16
-7.685360E-02	-4.214925E-03	7.881990E-01
-2.213293E-01	-9.170938E-03	2.233214E-01
-7.667119E-02	4.939755E-03	3.795433E-01
6.981638E-04	3.150673E-01	2.327583E-04

ROW 3

-1.581831E-02	1.229280E-03	1.000000E+00
-6.602666E-02	2.792882E-03	1.598517E-04
2.524046E-03	6.344310E-09	1.373842E-16
-2.552875E-01	-1.468662E-02	3.444456E-03
-8.992345E-04	-9.005566E-03	8.507267E-04
-2.545572E-01	-1.655193E-02	1.808635E-03
3.834832E-04	1.420893E-03	-4.315218E-04

ROW 4

-2.668310E-02	7.202371E-02	-6.602666E-02
1.000000E+00	-3.431968E-01	-1.207492E-02
-1.193902E-01	-9.030323E-08	-5.556151E-15
-8.632839E-01	2.354063E-03	7.864369E-02
6.072934E-02	2.490157E-02	-6.062869E-02
-8.663637E-01	-5.607174E-02	1.153540E-01
-6.992466E-04	-8.737567E-02	1.045641E-03

ROW 5

1.177548E-02	3.891926E-03	2.792882E-03
-3.431968E-01	1.000000E+00	-4.282966E-04
-2.980554E-03	-4.284343E-09	-2.383334E-16
1.311832E-01	1.080458E-02	3.299811E-03
3.011405E-03	6.856316E-03	-2.990340E-03
1.305544E-01	1.026482E-02	5.159812E-03
-2.988020E-04	-4.382503E-03	3.310169E-04

ROW 6

6.929133E-04	2.876543E-04	1.598517E-04
-1.207492E-02	-4.282966E-04	1.000000E+00
-1.743518E-04	-2.393632E-10	-1.420472E-17
6.486927E-03	6.761275E-04	3.080875E-04
2.055959E-04	4.056584E-04	-2.045788E-04
6.448101E-03	6.238668E-04	4.146811E-04

-1.767906E-05 -2.984292E-04 1.948999E-05

ROW 7

5.085410E-02	-3.649276E-03	2.524046E-03
-1.193902E-01	-2.980554E-03	-1.743518E-04
1.000000E+00	1.073607E-08	-9.848823E-16
9.414223E-02	3.902243E-02	-1.811607E-03
-5.152368E-03	3.520278E-02	5.155156E-03
9.047599E-02	1.198611E-02	-6.094502E-03
-1.587058E-03	6.872872E-03	1.562494E-03

ROW 8

-2.858162E-09	3.760610E-08	6.344310E-09
-9.030323E-08	-4.284343E-09	-2.393632E-10
1.073607E-08	1.000000E+00	3.640270E-22
5.901017E-08	-3.683120E-09	1.508187E-08
3.048469E-08	-3.099538E-09	-3.039602E-08
5.950368E-08	4.545345E-10	3.938933E-08
2.741542E-10	-4.351315E-08	-6.360046E-11

ROW 9

2.253158E-15	-1.779299E-16	1.373842E-16
-5.556151E-15	-2.383334E-16	-1.420472E-17
-9.848823E-16	3.640270E-22	1.000000E+00
4.224388E-15	2.065934E-15	-1.050262E-16
-2.024359E-16	1.460283E-15	2.113265E-16
4.070684E-15	1.156487E-15	-2.664861E-16
-6.163352E-17	2.750482E-16	6.892771E-17

ROW 10

5.547703E-02	-7.685360E-02	-2.552875E-01
-8.632839E-01	1.311832E-01	6.486927E-03
9.414223E-02	5.901017E-08	4.224388E-15
1.000000E+00	8.591576E-02	-8.762983E-02
-5.529414E-02	5.589282E-02	5.523345E-02
9.477173E-01	8.081586E-02	-1.160849E-01
-2.740186E-04	8.007227E-02	-3.831735E-05

ROW 11

4.246953E-01	-4.214925E-03	-1.468662E-02
2.354063E-03	1.080458E-02	6.761275E-04
3.902243E-02	-3.683120E-09	2.065934E-15
8.591576E-02	1.000000E+00	2.758438E-03
-3.744744E-03	7.488747E-01	4.142635E-03
8.738999E-03	4.360794E-01	4.007196E-03
-9.478438E-03	-8.806602E-03	9.654182E-03

ROW 12

-1.046218E-02	7.881990E-01	3.444456E-03
7.864369E-02	3.299811E-03	3.080875E-04
-1.811607E-03	1.508187E-08	-1.050262E-16
-8.762983E-02	2.758438E-03	1.000000E+00
4.070342E-01	9.739282E-03	-4.055440E-01
-8.628272E-02	-7.496466E-03	4.800576E-01

3.031051E-04 7.314821E-02 6.300848E-04

ROW 13

3.323813E-03	-2.213293E-01	-8.992345E-04
6.072934E-02	3.011405E-03	2.055959E-04
-5.152368E-03	3.048469E-08	-2.024359E-16
-5.529414E-02	-3.744744E-03	4.070342E-01
1.000000E+00	1.951405E-03	-9.998970E-01
-5.554982E-02	-4.317168E-03	1.866141E-01
2.344257E-04	-3.475381E-01	2.708153E-04

ROW 14

-2.716295E-01	-9.170938E-03	-9.005566E-03
2.490157E-02	6.856316E-03	4.056584E-04
3.520278E-02	-3.099538E-09	1.460283E-15
5.589282E-02	7.488747E-01	9.739282E-03
1.951405E-03	1.000000E+00	-1.818254E-03
-4.787881E-02	-2.614413E-01	8.818863E-03
-1.881336E-02	-1.409499E-02	1.879212E-02

ROW 15

-3.253701E-03	2.233214E-01	8.507267E-04
-6.062869E-02	-2.990340E-03	-2.045788E-04
5.155156E-03	-3.039602E-08	2.113265E-16
5.523345E-02	4.142635E-03	-4.055440E-01
-9.998970E-01	-1.818254E-03	1.000000E+00
5.546210E-02	4.588180E-03	-1.861885E-01
-1.802783E-04	3.483600E-01	-2.139272E-04

ROW 16

8.131903E-02	-7.667119E-02	-2.545572E-01
-8.663637E-01	1.305544E-01	6.448101E-03
9.047599E-02	5.950368E-08	4.070684E-15
9.477173E-01	8.738999E-03	-8.628272E-02
-5.554982E-02	-4.787881E-02	5.546210E-02
1.000000E+00	1.039037E-01	-1.170541E-01
-9.306631E-04	7.872082E-02	6.364167E-04

ROW 17

9.850321E-01	4.939755E-03	-1.655193E-02
-5.607174E-02	1.026482E-02	6.238668E-04
1.198611E-02	4.545345E-10	1.156487E-15
8.081586E-02	4.360794E-01	-7.496466E-03
-4.317168E-03	-2.614413E-01	4.588180E-03
1.039037E-01	1.000000E+00	-1.492974E-02
-2.306601E-02	1.486677E-02	2.345137E-02

ROW 18

-5.565664E-03	3.795433E-01	1.808635E-03
1.153540E-01	5.159812E-03	4.146811E-04
-6.094502E-03	3.938933E-08	-2.664861E-16
-1.160849E-01	4.007196E-03	4.800576E-01
1.866141E-01	8.818863E-03	-1.861885E-01
-1.170541E-01	-1.492974E-02	1.000000E+00

1.270007E-03 -7.521840E-01 1.496765E-03

ROW 19

1.200360E-02	6.981638E-04	3.834832E-04
-6.992466E-04	-2.988020E-04	-1.767906E-05
-1.587058E-03	2.741542E-10	-6.163352E-17
-2.740186E-04	-9.478438E-03	3.031051E-04
2.344257E-04	-1.881336E-02	-1.802783E-04
-9.306631E-04	-2.306601E-02	1.270007E-03
1.000000E+00	-1.122993E-03	-9.999058E-01

ROW 20

-6.366484E-04	3.150673E-01	1.420893E-03
-8.737567E-02	-4.382503E-03	-2.984292E-04
6.872872E-03	-4.351315E-08	2.750482E-16
8.007227E-02	-8.806602E-03	7.314821E-02
-3.475381E-01	-1.409499E-02	3.483600E-01
7.872082E-02	1.486677E-02	-7.521840E-01
-1.122993E-03	1.000000E+00	-1.286344E-03

ROW 21

-1.188562E-02	2.327583E-04	-4.315218E-04
1.045641E-03	3.310169E-04	1.948999E-05
1.562494E-03	-6.360046E-11	6.892771E-17
-3.831735E-05	9.654182E-03	6.300848E-04
2.708153E-04	1.879212E-02	-2.139272E-04
6.364167E-04	2.345137E-02	1.496765E-03
-9.999058E-01	-1.286344E-03	1.000000E+00

ADJUSTED OBJECT COORDINATES

POINT	X	Y	Z
5	0.0002	0.0607	0.2546
6	0.0001	0.0500	0.0508
7	0.0000	0.2539	0.0503
8	-0.0001	0.2530	0.2539
9	0.0507	0.2535	0.1524
10	0.1524	0.1531	0.1525
11	0.2538	0.0530	0.1527
12	0.1525	0.1529	0.0501
13	0.1525	0.1528	0.2543

STANDARD DEVIATIONS OF OBJECT COORDINATES (MM)

POINT	X	Y	Z
5	0.8230	0.6085	0.6057
6	0.8240	0.6056	0.6120
7	0.8226	0.5959	0.6137
8	0.8239	0.6599	0.6579
9	0.8231	0.5679	0.5393
10	0.8262	0.5213	0.5091
11	0.8247	0.6469	0.5960
12	0.8246	0.5486	0.6028
13	0.8222	0.5397	0.5530

FRAME photo LT

PRINCIPAL DISTANCE = -1118.1400 mm

ST. D. OF X = 0.4740 mm

$$ST. D. OF Y = 0.1740 \text{ mm}$$

CAMERA STATION PARAMETERS

P O S I T I O N

A T T I T U D E (Object to Photo)

```
X = 1.0337 m ST. D. = 60000.0000 m OMEGA = 91 17 43.0000 ST. D. = 90 0 0.0000
Y = 0.1281 m ST. D. = 60000.0000 m PHI = 89 35 11.0000 ST. D. = 90 0 0.0000
Z = 0.1362 m ST. D. = 60000.0000 m KAPPA = - 1 29 38.0000 ST. D. = 90 0 0.0000
```

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y	ID	X	Y	ID	X	Y
5	-93.0270	128.9220	6	-103.4630	-94.3720	7	119.8060	-94.5970	8	118.1420	128.9830
9	125.2420	18.3210	10	13.1590	20.0770	11	-127.1840	22.9390	12	13.4730	-110.8070
13	12.5050	151.1270									

O B J E C T C O N T R O L D A T A

1	X =	0.0510 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.0000 m	ST. D. =	0.0003	
	Z =	0.0510 m	ST. D. =	0.0003	
2	X =	0.2540 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.0000 m	ST. D. =	0.0003	
	Z =	0.0510 m	ST. D. =	0.0003	
3	X =	0.2540 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.0000 m	ST. D. =	0.0003	
	Z =	0.2540 m	ST. D. =	0.0003	
4	X =	0.0510 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.0000 m	ST. D. =	0.0003	
	Z =	0.2540 m	ST. D. =	0.0003	
5	X =	0.0000 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.0620 m	ST. D. =	0.0003	
	Z =	0.2540 m	ST. D. =	0.0003	
6	X =	0.0000 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.0510 m	ST. D. =	0.0003	
	Z =	0.0510 m	ST. D. =	0.0003	
7	X =	0.0000 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.2540 m	ST. D. =	0.0003	
	Z =	0.0510 m	ST. D. =	0.0003	
8	X =	0.0000 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.2540 m	ST. D. =	0.0003	
	Z =	0.2540 m	ST. D. =	0.0003	
9	X =	0.0510 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.2540 m	ST. D. =	0.0003	
	Z =	0.1520 m	ST. D. =	0.0003	
10	X =	0.1520 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.1520 m	ST. D. =	0.0003	
	Z =	0.1520 m	ST. D. =	0.0003	

O B J E C T C O N T R O L D A T A

11	X =	0.2540 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.0510 m	ST. D. =	0.0003	
	Z =	0.1520 m	ST. D. =	0.0003	
12	X =	0.1520 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.1520 m	ST. D. =	0.0003	
	Z =	0.0510 m	ST. D. =	0.0003	
13	X =	0.1520 m	ST. D. =	0.0003	TYPE = 0
	Y =	0.1520 m	ST. D. =	0.0003	
	Z =	0.2540 m	ST. D. =	0.0003	

C A M E R A S T A T I O N S C O R R E C T I O N S

ITERATION 1

photo AP	POSITION	-0.0028	-0.0005	-0.0027 m.	ATTITUDE	-0.001604662	0.001694444	0.000277380
photo LT	POSITION	-0.0160	-0.0118	-0.0013 m.	ATTITUDE	0.174346766	-0.021565908	-0.172999557

PROVISIONAL WEIGHTED SUM OF SQUARES = 5311.91

ITERATION 2

photo AP	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	-0.000006254	0.000019220	0.000005725
photo LT	POSITION	0.0002	0.0004	0.0000 m.	ATTITUDE	-0.127972014	0.000434791	0.127913699

PROVISIONAL WEIGHTED SUM OF SQUARES = 5478.37

ITERATION 3

photo AP	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	0.000000407	-0.000000755	0.000000043
photo LT	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	-0.001261961	-0.000235849	0.001262798

PROVISIONAL WEIGHTED SUM OF SQUARES = 451.502

ITERATION 4

photo AP	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	0.000000019	-0.000000007	0.000000001
photo LT	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	0.000010750	-0.000000149	-0.000010787

PROVISIONAL WEIGHTED SUM OF SQUARES = 449.517

TRIANGULATED OBJECT POINTS RESIDUALS

(in micrometers)

1 *0* photo AP

-21

-27

2 *0* photo AP

52

12

3 *0* photo AP

-102

-19

4 *0* photo AP

54

6

9 *0* photo AP photo LT

-48 690

-33 21

10 *0* photo AP photo LT

32 287

-39 127

11 *0* photo AP photo LT

-30 -831

-14 12

12 *0* photo AP photo LT

25 334

71 -137

13 *0* photo AP photo LT

36 523

43 -30

5 *0* photo LT

431

-39

TRIANGULATED OBJECT POINTS RESIDUALS

(in micrometers)

6 *0* photo LT
-494
-89

7 *0* photo LT
-870
263

8 *0* photo LT
-27
-126

WEIGHTED SUM OF SQUARES (CAMERA) =	0.0
WEIGHTED SUM OF SQUARES (OBJECT) =	42.2
WEIGHTED SUM OF SQUARES (PLATES) =	21.1
WEIGHTED SUM OF SQUARES (TOTAL) =	63.3
DEGREES OF FREEDOM..... =	24

a posteriori ESTIMATES FOR UNIT WEIGHT

VARIANCE =	2.638
ST. DEV. =	1.624

* M-SQUARED SYSTEMS, INC. *

FIDUCIAL MEASUREMENTS OF FRAME 3

ID	AVERAGE		MAX SPREAD	
	X	Y	X	Y
111	133.685	12.878	0.000	0.000
222	137.728	166.892	0.000	0.000
333	444.350	163.111	0.000	0.000
444	440.031	9.712	0.000	0.000

4-PARAMETER RESIDUALS OF THE FIDUCIAL COORDINATES

111	0.328	-0.964
222	0.157	1.135
333	-0.484	-0.163
444	-0.002	-0.007

PLATE COORDINATES

ID	MEASURED		ADJUSTED		MAX SPREAD		FRAME
	X	Y	X	Y	X	Y	
1	318.755	167.451	28.263	79.106	0.000	0.000	3
2	235.609	163.964	-54.736	74.442	0.000	0.000	3
3	255.882	182.144	-34.745	92.889	0.000	0.000	3
4	218.752	177.223	-71.762	87.446	0.000	0.000	3
5	336.703	236.797	45.205	148.626	0.000	0.000	3
6	233.300	229.918	-57.979	140.286	0.000	0.000	3
7	233.296	231.868	-58.011	142.234	0.000	0.000	3
8	286.428	129.312	-3.485	40.553	0.000	0.000	3

* M-SQUARED SYSTEMS, INC. *
FIDUCIAL MEASUREMENTS OF FRAME 4

ID	AVERAGE		MAX SPREAD	
	X	Y	X	Y
111	85.888	32.534	0.000	0.000
222	90.638	186.617	0.000	0.000
333	397.229	181.456	0.000	0.000
444	392.258	28.046	0.000	0.000

4-PARAMETER RESIDUALS OF THE FIDUCIAL COORDINATES

111	0.326	-1.000
222	0.181	1.170
333	-0.507	-0.157
444	0.000	-0.014

PLATE COORDINATES

ID	MEASURED		ADJUSTED		MAX SPREAD		FRAME
	X	Y	X	Y	X	Y	
1	307.611	185.317	64.181	78.750	0.000	0.000	4
2	213.476	183.183	-29.786	74.868	0.000	0.000	4
3	287.331	200.163	43.653	93.198	0.000	0.000	4
4	244.258	197.263	0.692	89.501	0.000	0.000	4
5	330.651	251.473	85.960	145.244	0.000	0.000	4
6	189.265	249.232	-55.193	140.377	0.000	0.000	4
7	257.829	249.594	13.271	142.013	0.000	0.000	4
8	263.184	148.467	20.500	41.124	0.000	0.000	4

* M-SQUARED SYSTEMS, INC. *

APR 1988 VERSION

C. J. MUGNIER

CALIBRATED FIDUCIAL COORDINATES

111	-152.586	-77.293
222	-154.779	77.292
333	154.780	77.815
444	157.005	-77.824

LENS DISTORTION

RADIAL PARAMETERS

K1= 0.00000000E+00 K2= 0.00000000E+00 K3= 0.00000000E+00 K4= 0.00000000E+00 K5= 0.00000000E+00 K6= 0.00000000E+00

LENS DECENTRATION PARAMETERS

J1= 0.00000000 J2= 0.00000000E+00 PHI= 0.00000000E+00

* M-SQUARED SYSTEMS, INC. *

FIDUCIAL MEASUREMENTS OF FRAME 1

ID	AVERAGE		MAX SPREAD	
	X	Y	X	Y
111	102.561	2.059	0.000	0.000
222	97.094	156.912	0.000	0.000
333	406.717	164.127	0.000	0.000
444	412.749	8.538	0.000	0.000

4-PARAMETER RESIDUALS OF THE FIDUCIAL COORDINATES

111	-0.088	-0.053
222	0.086	0.096
333	-0.170	-0.100
444	0.172	0.057

PLATE COORDINATES

ID	MEASURED		ADJUSTED		MAX SPREAD		FRAME
	X	Y	X	Y	X	Y	
1	266.915	171.536	15.189	88.217	0.000	0.000	1
2	216.391	171.483	-35.257	89.287	0.000	0.000	1
3	327.475	191.734	76.104	107.039	0.000	0.000	1
4	303.948	189.371	52.561	105.202	0.000	0.000	1
5	280.564	241.856	30.379	158.125	0.000	0.000	1
6	188.340	253.542	-61.442	171.841	0.000	0.000	1
7	306.731	249.982	56.686	165.657	0.000	0.000	1
8	233.997	130.944	-18.579	48.420	0.000	0.000	1

* M-SQUARED SYSTEMS, INC. *

FIDUCIAL MEASUREMENTS OF FRAME 2

ID	AVERAGE		MAX SPREAD	
	X	Y	X	Y
111	108.923	3.622	0.000	0.000
222	104.779	158.082	0.000	0.000
333	413.837	161.969	0.000	0.000
444	418.012	6.748	0.000	0.000

4-PARAMETER RESIDUALS OF THE FIDUCIAL COORDINATES

111	0.082	-0.037
222	-0.079	0.115
333	-0.078	-0.109
444	0.074	0.031

PLATE COORDINATES

ID	MEASURED		ADJUSTED		MAX SPREAD		FRAME
	X	Y	X	Y	X	Y	
1	207.134	168.695	-52.228	86.845	0.000	0.000	2
2	217.724	171.454	-41.590	89.485	0.000	0.000	2
3	286.853	184.688	27.795	101.935	0.000	0.000	2
4	293.625	185.565	34.587	102.735	0.000	0.000	2
5	209.378	235.885	-49.199	154.109	0.000	0.000	2
6	203.423	251.858	-54.977	170.174	0.000	0.000	2
7	285.649	239.268	27.224	156.610	0.000	0.000	2
8	199.051	130.261	-60.770	48.449	0.000	0.000	2

GIANT RUN OF RHESUS DATA:

FRAME AP 45

PRINCIPAL DISTANCE = -1820.0900 mm

ST. D. OF X = 0.8500 mm

ST. D. OF Y = 0.9500 mm

CAMERA STATION PARAMETERS

P O S I T I O N

A T T I T U D E (Object to Photo)

X =	-0.9377 m	ST. D. =	0.1000 m	OMEGA =	92 35 48.0000	ST. D. =	01 00 0.0000
Y =	1.3065 m	ST. D. =	0.1000 m	PHI =	220 57 31.0000	ST. D. =	01 00 0.0000
Z =	0.1957 m	ST. D. =	0.0022 m	KAPPA =	02 57 0.0000	ST. D. =	01 00 0.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y	ID	X	Y	ID	X	Y
lam	28.2630	79.1060	ram	-54.7360	74.4420	lom	-34.7450	92.8890	rom	-71.7620	87.4460
ltp	45.2050	148.6260	rtp	-57.9790	140.2860	ctp	-58.0110	142.2340	neck	-3.4850	40.5530

FRAME AP 90

PRINCIPAL DISTANCE = -1820.0900 mm ST. D. OF X = 0.8500 mm ST. D. OF Y = 0.9500 mm

CAMERA STATION PARAMETERS

P O S I T I O N

A T T I T U D E (Object to Photo)

X =	0.0408 m	ST. D. =	0.0000 m	OMEGA =	91 19 27.0000	ST. D. =	00 00 1.0000
Y =	1.7281 m	ST. D. =	0.0000 m	PHI =	183 27 18.0000	ST. D. =	00 00 1.0000
Z =	0.1769 m	ST. D. =	0.0000 m	KAPPA =	00 11 31.0000	ST. D. =	00 00 1.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y	ID	X	Y	ID	X	Y
lam	64.1810	78.7500	ram	-29.7860	74.8680	lom	43.6530	93.1980	rom	0.6920	89.5010
ltp	85.9600	145.2440	rtp	-55.1930	140.3770	ctp	13.2710	142.0130	neck	20.5000	41.1240

FRAME LAT 45

PRINCIPAL DISTANCE = -1118.1400 mm

ST. D. OF X = 0.8500 mm

ST. D. OF Y = 0.9500 mm

CAMERA STATION PARAMETERS

P O S I T I O N

A T T I T U D E (Object to Photo)

X =	0.8416 m	ST. D. =	0.1000 m	OMEGA =	90 09 57.0000	ST. D. =	01 00 0.0000
Y =	0.6097 m	ST. D. =	0.1000 m	PHI =	124 43 26.0000	ST. D. =	01 00 0.0000
Z =	0.1395 m	ST. D. =	0.0014 m	KAPPA =	00 12 44.0000	ST. D. =	01 00 0.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y	ID	X	Y	ID	X	Y
lam	15.1890	88.2170	ram	-35.2570	89.2870	lom	76.1040	107.0390	rom	52.5610	105.2020
ltp	30.3790	158.1250	rtp	-61.4420	171.8410	ctp	56.6860	165.6570	neck	-18.5790	48.4200

FRAME LAT 90

PRINCIPAL DISTANCE = -1118.1400 mm ST. D. OF X = 0.8500 mm ST. D. OF Y = 0.9500 mm

CAMERA STATION PARAMETERS

P O S I T I O N

A T T I T U D E (Object to Photo)

X =	1.0179 m	ST. D. =	0.0014 m	OMEGA =	93 52 50.0000	ST. D. =	01 00 0.0000
Y =	0.1168 m	ST. D. =	0.0025 m	PHI =	88 21 44.0000	ST. D. =	00 09 12.0000
Z =	0.1348 m	ST. D. =	0.0014 m	KAPPA =	- 04 00 19.0000	ST. D. =	01 00 0.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y	ID	X	Y	ID	X	Y
lam	-52.2280	86.8450	ram	-41.5900	89.4850	lom	27.7950	101.9350	rom	34.5870	102.7350
ltp	-49.1990	154.1090	rtp	-54.9770	170.1740	ctp	27.2240	156.6100	neck	-60.7700	48.4490

C A M E R A S T A T I O N S C O R R E C T I O N S

ITERATION 1

AP 45	POSITION	0.0098	-0.0020	0.0002 m.	ATTITUDE	-0.000108881	-0.003053443	0.001714348
AP 90	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	0.000000014	-0.000000005	-0.000000001
LAT 45	POSITION	0.0049	-0.0053	0.0000 m.	ATTITUDE	0.000242430	-0.010253587	0.000166286
LAT 90	POSITION	0.0002	0.0003	0.0007 m.	ATTITUDE	-0.001849999	0.000256616	-0.004527043

PROVISIONAL WEIGHTED SUM OF SQUARES = 85.1946

ITERATION 2

AP 45	POSITION	0.0004	0.0008	0.0000 m.	ATTITUDE	-0.000013969	-0.000510223	-0.000076011
AP 90	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	0.000000000	0.000000000	0.000000000
LAT 45	POSITION	0.0000	-0.0002	0.0000 m.	ATTITUDE	-0.000012762	-0.000106980	-0.000088601
LAT 90	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	0.000049932	-0.000003111	0.000035520

PROVISIONAL WEIGHTED SUM OF SQUARES = 45.2577

ITERATION 3

AP 45	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	0.000000018	-0.000000050	0.000002101
AP 90	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	0.000000000	0.000000000	0.000000000
LAT 45	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	-0.000000268	0.000000557	-0.000004729
LAT 90	POSITION	0.0000	0.0000	0.0000 m.	ATTITUDE	-0.000003528	-0.000000017	-0.000003724

PROVISIONAL WEIGHTED SUM OF SQUARES = 45.2386

TRIANGULATED IMAGE POINTS RESIDUALS

(in micrometers)

lam	AP 45	AP 90	LAT 45	LAT 90
	-54	29	28	-58
	-655	518	132	15
ram	AP 45	AP 90	LAT 45	LAT 90
	2116	-1552	21	1091
	-66	-767	724	-58
lom	AP 90	AP 45	LAT 45	LAT 90
	931	-1055	-318	-365
	172	276	-277	-116
rom	LAT 45	AP 45	AP 90	LAT 90
	847	194	-759	-721
	587	1473	-648	-1411
ltp	AP 45	AP 90	LAT 45	LAT 90
	-17	-167	412	-360
	-953	623	18	332
rtp	AP 45	LAT 45	AP 90	LAT 90
	-2089	-756	2179	-353
	-27	-625	-403	1033
ctp	LAT 45	AP 90	AP 45	LAT 90
	2	-254	327	229
	-716	-2	270	501
neck	AP 45	LAT 45	AP 90	LAT 90
	587	-212	-333	510
	-321	165	213	-72

WEIGHTED SUM OF SQUARES (CAMERA) =	0.8
WEIGHTED SUM OF SQUARES (OBJECT) =	0.0
WEIGHTED SUM OF SQUARES (PLATES) =	44.4
WEIGHTED SUM OF SQUARES (TOTAL) =	45.2
DEGREES OF FREEDOM..... =	40

a posteriori ESTIMATES FOR UNIT WEIGHT

VARIANCE =	1.131
ST. DEV. =	1.063

TRIANGULATED CAMERA STATIONS

IDENT	POSITION	COVARIANCE MATRIX	ATT(Object to Photo)	COVARIANCE MATRIX
AP 45	X = -0.9276 m.	+1.822E-04 +4.110E-05 +9.948E-08	OMEGA = 92 35 22.6640	+4.059E-06 +3.096E-06 +6.962E-07
	Y = 1.3052 m.	+4.110E-05 +2.114E-04 -2.700E-07	PHI = 220 45 15.9307	+3.096E-06 +8.797E-05 +7.907E-06
	Z = 0.1958 m.	+9.948E-08 -2.700E-07 +5.312E-06	KAPPA = 03 02 38.3646	+6.962E-07 +7.907E-06 +5.830E-05
AP 90	X = 0.0408 m.	+1.131E-10 -7.877E-17 -4.995E-16	OMEGA = 91 19 27.0029	+2.658E-11 +7.156E-17 +8.394E-18
	Y = 1.7281 m.	-7.877E-17 +1.131E-10 -1.707E-16	PHI = 183 27 17.9990	+7.156E-17 +2.658E-11 -9.574E-19
	Z = 0.1769 m.	-4.995E-16 -1.707E-16 +1.131E-10	KAPPA = 00 11 30.9999	+8.394E-18 -9.574E-19 +2.658E-11
LAT 45	X = 0.8405 m.	+4.343E-05 -9.315E-06 -1.574E-07	OMEGA = 90 10 44.3170	+1.097E-05 +1.054E-06 -4.841E-06
	Y = 0.6043 m.	-9.315E-06 +7.434E-05 -1.654E-07	PHI = 124 07 49.0944	+1.054E-06 +8.469E-05 +5.588E-06
	Z = 0.1395 m.	-1.574E-07 -1.654E-07 +2.055E-06	KAPPA = 00 12 59.0481	-4.841E-06 +5.588E-06 +6.255E-05
LAT 90	X = 1.0181 m.	+2.069E-06 -9.374E-08 -1.748E-07	OMEGA = 93 46 37.9819	+1.853E-04 +1.301E-06 -1.445E-04
	Y = 0.1171 m.	-9.374E-08 +6.835E-06 -1.980E-07	PHI = 88 22 36.2858	+1.301E-06 +7.447E-06 -1.185E-06
	Z = 0.1355 m.	-1.748E-07 -1.980E-07 +3.328E-07	KAPPA = -04 15 46.2114	-1.445E-04 -1.185E-06 +1.837E-04

SUMMARY STATISTICS FOR CAMERA STATIONS

RMS FOR STANDARD DEVIATIONS

COUNT = 4	X =	0.0075 m.	OMEGA =	00 24 19.5803
	Y =	0.0086 m.	PHI =	00 23 4.0940
	Z =	0.0014 m.	KAPPA =	00 29 59.8426

CONCLUSIONS:

There is apparently an error of uncertainty in positions in the Object Space:

X axis of 0.7 millimeters,

Y axis of 3.7 millimeters,

Z axis of 0.5 millimeters.

(This "Y axis" corresponds to the SUBJECT's Sagittal Plane.)

Until modifications are implemented in the Photogrammetric X-Ray Anthropometric System, this is the maximum achievable accuracy.

TRIANGULATED OBJECT POINTS

IDENT	POSITION (meters)	COVARIANCE MATRIX	STANDARD DEV (m)
neck	X = 0.1214	+4.569E-07 -6.436E-07 +2.565E-09	0.0007
	Y = 0.0945	-6.436E-07 +1.299E-05 -1.547E-07	0.0036
	Z = 0.1763	+2.565E-09 -1.547E-07 +3.054E-07	0.0006
ctp	X = 0.1242	+4.271E-07 -6.868E-07 +1.412E-08	0.0007
	Y = 0.1654	-6.868E-07 +1.372E-05 -6.535E-07	0.0037
	Z = 0.2628	+1.412E-08 -6.535E-07 +3.102E-07	0.0006
rtp	X = 0.1869	+5.657E-07 -1.075E-06 +6.287E-09	0.0008
	Y = 0.1006	-1.075E-06 +1.316E-05 -3.555E-07	0.0036
	Z = 0.2646	+6.287E-09 -3.555E-07 +2.989E-07	0.0005
ltp	X = 0.0627	+4.656E-07 -2.534E-07 -1.907E-08	0.0007
	Y = 0.1029	-2.534E-07 +1.460E-05 -5.294E-07	0.0038
	Z = 0.2695	-1.907E-08 -5.294E-07 +3.155E-07	0.0006
rom	X = 0.1351	+4.365E-07 -7.602E-07 +1.386E-08	0.0007
	Y = 0.1695	-7.602E-07 +1.311E-05 -4.470E-07	0.0036
	Z = 0.2171	+1.386E-08 -4.470E-07 +2.812E-07	0.0005
lom	X = 0.0970	+4.136E-07 -4.730E-07 +6.388E-09	0.0006
	Y = 0.1665	-4.730E-07 +1.353E-05 -4.763E-07	0.0037
	Z = 0.2210	+6.388E-09 -4.763E-07 +2.862E-07	0.0005
ram	X = 0.1665	+4.856E-07 -9.456E-07 +5.025E-09	0.0007
	Y = 0.1109	-9.456E-07 +1.267E-05 -2.500E-07	0.0036
	Z = 0.2054	+5.025E-09 -2.500E-07 +2.660E-07	0.0005
lam	X = 0.0818	+4.244E-07 -3.862E-07 -1.741E-09	0.0007
	Y = 0.1004	-3.862E-07 +1.368E-05 -2.771E-07	0.0037
	Z = 0.2103	-1.741E-09 -2.771E-07 +2.880E-07	0.0005

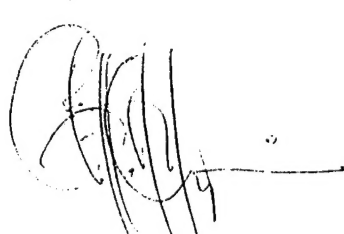
SUMMARY STATISTICS FOR OBJECT POINTS

RMS FOR STANDARD DEVIATIONS

COUNT = 8	X =	0.0007 meters
COUNT = 8	Y =	0.0037 meters
COUNT = 8	Z =	0.0005 meters

RECOMMENDATIONS:

1. Shorten X-Ray Focal Lengths to improve System Geometry.
2. Add extra BB's to X-Ray Plate Carriers to enhance ability to compensate for film shrinkage due to high development temperatures.
3. Add extra BB's to X-Rays of all subjects (temporary "stick-ons") to enhance geometry of photogrammetric solutions.
(Absolute MINIMUM number of well-identifiable points appearing on all imagery of the same subject should be NINE well-spaced small BB's ON THE SUBJECT, regardless of species.)
4. Rotate Calibration Prism twice, resulting in 3 different "AP" X-Rays and 3 different "LAT" X-Rays for each calibration.
5. Purchase and use a Back-Lit X-Y digitizer for all X-Ray Anthropometric applications with an accuracy of plus or minus 0.001 inches. Digitize the actual X-Rays; not paper tracings.
6. Enhance interactive Input/Output of GIANT solutions with graphics for solution of eigenvectors/eigenvalues of output covariance matrices.
7. Produce perspective 3-D plots of error ellipsoids in solutions.
8. Merge GIANT system into existing Anthropometry system.
9. Perform re-evaluation of system accuracy after implementation of recommendations 1-4.
10. Modify GIANT system for dynamic camera calibration for capability to recompute all X-Ray and all Photographic Runs ever done at NBDL for maximum reliability and individual frame & sled run positional accuracy assessment.

 4 May 90
CLIFFORD J. MUGNIER
CERTIFIED PHOTOGRAMMETRIST (ASP No. 236)